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ABSTRACT

This paper describes an effort to demonstrate the benefits of an innovative, lightweight, lubrication free centrifugal compressor that allows the use of environmentally safe alternate refrigerants with improved system efficiencies over current State-of-the-Art technology. This effort couples the recently developed 3-D high efficiency centrifugal compressor and fabrication technologies with magnetic bearing technology and will then prove the performance, life and reliability of the compressor.

INTRODUCTION

The manufacture of CFCs will be halted by 1 January 1996 and HCFCs will be the next to be totally phased out. All DoD vapor compression environmental control systems use these refrigerants. The proposed environmentally safe alternate refrigerants (e.g., R-134a) are inherently less stable than the currently used CFCs, so that they break down in the lower atmosphere, and thus do not degrade the ozone layer. These refrigerants have zero ozone depletion factor. The addition of lubricants further lowers stability. In the pure state, these fluids remain relatively stable to temperatures up to 370°C. But, the presence of oil lowers the stability limits to below 100°C. The oil unfortunately acts as a catalyst for the decomposition process, which means they will more readily decompose within the refrigeration cycle hardware. This can preclude the use of vapor compression cycle technology unless compromises are made that substantially lower efficiency, reliability and lifetime.

The vapor compression heat pump remains the most efficient refrigeration and air conditioning cycle available. Rather than discard this cycle for less efficient cooling cycles such as magnetic refrigeration, Stirling, Brayton, thermoelectric, or a rash of others, the development of a lubrication free compressor would allow the well known vapor compression cycle to be used without destroying the ozone layer. Removal of the oil means very good HFC refrigerant stability. Furthermore the use of one of these "NEW" cycles will mean retraining the HVAC technician community, retrofitting the existing HVAC and refrigeration units in the country, sacrificing efficiency, and costing more to procure, operate and maintain. Thus Wright Laboratory has contracted with Mainstream Engineering Corporation to develop a low cost high efficiency HFC lubrication free compressor for new and retrofit HVAC applications.

In this effort, we will prove the benefits of an innovative, lightweight, lubrication free HFC compressor that can be used with these new environmentally safe non-ozone-depleting refrigerants (such as HFC-134a, HFC-227, HFC-236, HFC-245 or any other new refrigerants yet to be developed).

This program's technological heritagecomes from the space program. It results from the desire for an ultra reliable heat pump thermal management system for spacecraft to reduce the size of the payload radiators. Reliability and life concerns drove the design to a non-mechanical contact system. Thus we are applying spacecraft sponsored technology to solve terrestrial problems. These previous efforts were funded through the Small Business Innovative Research (SBIR) Program. Several Phase 1 and Phase 2 programs resulted and this current effort is a Phase 2 SBIR program. These efforts resulted in the preliminary design of a long life, high reliability, high performance, lightweight, magnetic bearing centrifugal compressor and have included the testing and development of innovative compressor impellers and diffusers and the demonstration of magnetic bearings and control electronics similar to those required for this effort.

For this effort, we will extensively test an innovative compressor for use in commercial HVAC applications that will allow the use of the vapor compression refrigeration cycle with any HFC non-ozone depleting refrigerant and will result in the development of hardware that can be field tested in an Air Force HVAC application. Due to the current environmental issues

associated with CFC and HCFC refrigeration and air conditioning, we anticipate tremendous commercial retrofit possibilities and new air conditioning and refrigeration applications. The proposed units will allow the straightforward conversion of existing units to HFC refrigerants as well as the production of new environmentally safe vapor compression refrigeration and air conditioning systems.

THE INNOVATIONS

The proposed compressor system has many advantages when compared to traditional compressors. Limitations of traditional compressors for aerospace applications have been well documented by the authors and others; mechanical life and performance is limited when contact type bearings are used, and the presence of oil as a lubricant in the system serves to reduce thermal stability and efficiency. The use of environmentally friendly HFC refrigerants further stresses the stability issue.

We are designing the proposed compressor with innovative technology, which will result in an extremely reliable and long-life compressor. We considered other compressor designs, including scroll, screw, rotary, and reciprocating; but, the centrifugal compressor is better suited for this nonlubricated HFC compressor to replace existing CFC-12, CFC-11, CFC-114, and HCFC-22 vapor-compression refrigerators, air conditioners, and heat pumps. The 3-D centrifugal compressor is the clear design choice because it produces pressure by using angular momentum and not by positive displacement methods. Several advantages include: a) the mechanics of operation are relatively simple and inherently reliable due to the elimination of mechanical contact between internal parts; b) there are no valves within the system; c) the pressure produced is continuous, unlike that of a positive-displacement compressor; d) there is no need for lubricant (resulting in extremely high thermal stability limits and no need for oil separators); and e) the compressor's speed can be modulated without bearing contact to match the demand as a result of the magnetic bearing and control electronics thereby reducing unnecessary power consumption.

Under previous efforts, we preliminarily designed an innovative centrifugal compressor that uses magnetic bearings to support the rotor structure. Under another effort, we developed the impeller test facility, rapid prototyping machining system, and impeller modeling capability, as well as performing the overall system integration of the compressor impellers and diffusers with the motor bearings and control electronics.

Various design improvements in the geometry of the centrifugal impeller and the automated design and manufacturing of the 3-D impellers and diffusers has occurred since the original Phase 1 effort in this area.

This Phase 2 effort will investigate the variables in impeller and diffuser design for HFC refrigerants. Our integrated 3-D lubrication free compressor design will surpass existing technology in efficiency and reliability. Novel ideas, such as the inverting the impellers, have eliminated the requirement to bleed off working fluid in order to provide bearing and motor cooling and allows the motor housing to act as the liquid accumulator. This greatly improves performance and improves the reliability and saves mass and lowers cost by reducing the number of required components in the system. Magnetic bearings generate very little heat compared to contact-type bearings although the motor armature will still require cooling. The motor will be 90% efficient. In our preliminary design, the inlet refrigerant will pass over the motor armature, thus providing motor and bearing cooling.

There are significant advantages of using a 3-D verses 2-D compressor design. 2-D blades are generally radial at both the entrance and exit while 3-D blades are predominately axial at the entrance and radial at the exit. Thus 3-D compressors have relatively long blades and these serve to smooth the fluid flow. The portion of the blade at the axial face functions as an inducer that guides the flow from axial to radial. This increases the static enthalpy and pressure by increasing the reduction of relative velocity from inlet to outlet. This also improves compressor efficiency and results in less flow resistance. Another advantage of the 3-D design is that it is usually unshrouded which allows for higher speeds because of substantially lower stresses. We are able to use a 3-D compressor because of our analytic capability, improved manufacturing capabilities, and because the magnetic bearing allows the higher speed. These capabilities result from the previous programs.

Compressor efficiencies are closely related to the compressor size, flowrate, pressure rise and working fluid. Efficiency typically decreases as rotor size decreases. For large, low pressure ratio air compressors, the efficiency reaches 90%, while for large, high pressure air compressors the efficiency is nearer to 80%. In terms of small centrifugal compressors, as we have proposed for this application, there are numerous 2-D compressors that are basically 1950's designs. Few, if any, 3-D small compressors have been developed and none have been published in the literature. We expect that this compressor will be 5-10% more efficient compared to current S-O-T-A designs. In addition, removal of the lubricant will result in a 15-20% increase in COP compared to current CFC-12 and HCFC-22 systems and even more when compared to HFC-134a systems. If our goals are met, this will result in significant operating costs savings.

Substantial technological advances have occurred during the last decade that have an appreciable impact on the performance and feasibility of magnetic bearings for spacecraft power applications. These advances in technology include improved magnetic materials,

improved semiconductor power electronics, improved digital electronics, better control system technology, and improved sensors. These developments allow lightweight, highly reliable magnetic bearings to be constructed (which would not have been feasible several years ago).

Because we eliminated all mechanical contact of the rotating parts, the life of the electronics dictates the life of the compressor. This is very predictable, and long term life can be provided by electronics redundancy. We designed the compressor with touch down pads to avoid compressor damage if the electronics should fail. The application of contact free, or in our application, magnetic bearings is not new and has been applied to large industrial centrifugal compressors with great success. It is only recently that further developments in micro-electronics would allow the application of magnetic, contact free bearings to small applications such as this compressor. Similarly, new developments in electric motor design provide increased specific power and speed with improved efficiency. The magnetic bearing and control electronic's development has already been demonstrated by Mainstream's electronic's partner in this effort: SatCon Technology, during an earlier effort.

Further advantages of the integrated magnetic bearings will be the ability to increase the rotational speeds within fluid flow limitations thereby allowing a reduction in size of the impeller and casing and reducing mass and cost. Magnetic bearings also will correct any minute out of balance forces inherent in the rotating structure. Magnetic bearings use active feedback control to positively maintain the impeller positioned in the correct place regardless of minute imbalances in the rotor structure. When coupled with shrouded designs, lower tolerances and reduced costs will result. The feedback also provides on-line diagnostic information on compressor performance.

We considered foil (gas) bearings, but they will still require lubrication during spin-up. Magnetic bearings levitate the rotor before spinning, and thus are non-contact bearings at all speeds which also allows variable speed operation.

In addition to the removing the working fluid breakdown and the noncondensible gas separator associated with it, no oil in the system means; improved heat transfer in the evaporator and condenser, no need for an oil separator and no concerns about oil cooling in micro- or high applications.

The major objective of this innovative design is to attain lightweight, long-life, lubrication free HFC vapor compression operation. The proposed magnetic bearing design generates less heat than contact type bearings and is not dependent on the ability of the working fluid to keep them cool. Also, no need for oil lubrication or an oil separator further simplifies the overall system design. The use of an innovative impeller design and motor/control assembly will allow high speed AND variable speed operation, thereby reducing system mass at maximum capacity and reducing energy consumption at part-load by using load following. We also intend to explore the use of lightweight materials in the manufacture of the prototype compressor.

CONCLUSION

This paper has briefly addressed the benefits of this HFC refrigeration compressor for various HVAC commercial and military applications. The successful completion of this effort will result in a finalized design and hardware implementation of an innovative refrigeration compressor for new and retrofit HVAC applications. During this program, we will demonstrate the performance, cost, reliability, and long term operation (to name but a few) of this compressor. We anticipate

Table 1. Key Features of the Mainstream Centrifugal Compressor

* Inverted impeller design with inlet refrigerant to cool the motor; Reduced magnetic-bearing thrust load and inherent motor cooling.
* High-reliability, non-contact magnetic bearings with self-balancing ability--reduces transmitted vibration and noise and eliminates the need for oil in the system, thereby increasing thermal efficiency and thermal stability, and removes the requirement for an oil separator.
* Integrated motor/bearing control package.
* Variable speed--ability to adjust to load demands, which allows operation at maximum efficiency and allows load following.
* Optimized impeller/diffuser design, which we developed specifically for HFC fluid to be compressed.
* Highly efficient motor design and low frictional resistance, which reduces power consumption.

additional new and retrofit HVAC applications, as well as in other military systems and also considerable dual-use potential.

The proposed magnetic bearing centrifugal compressor incorporates numerous innovative ideas including the motor cooling design, variable speed operation, high efficiency two stage rotor/diffuser design, and low power non-contact magnetic bearing configuration. This effort will demonstrate this innovative compressor for HFC vapor compression refrigeration and air conditioning systems where the use of lubrication causes a stability problem, and high efficiency and low cost are also significant concerns.

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